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Abstract

DEVELOPMENT OF ZIRCONIUM-NIOBIUM ALLOYS

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1. Data have been obtained which give considerable confidence in zirconium - 2.5wt% niobium alloys for use in water-cooled power reactors. A number of distinct advantages over the use of Zircaloy-2 can result.
2. The alloys studied, Zr - 2.5wt% Nb and Zr - 2.5wt% Nb - 0.5wt% Cu have contained ~ 1100 ppm oxygen as the major impurity. The best combination of strength, ductility and corrosion resistance found thus far is given by the heat treatments:

Zr - 2.5wt% Nb: water quench from 850-880°C
temper up to 24 h at 500°C

Zr - 2.5wt% Nb - 0.5wt% Cu: water quench from 825-850°C
temper 6 h at 535°C

The cold-worked condition is under investigation.

3. In the heat-treated condition, each alloy has an ultimate tensile strength at 300°C $>56 \text{ kgf/mm}^2$, with a reduction in area of 70%. Neutron irradiation up to integrated fluxes of 10^{21} cm^{-2} ($E > 500 \text{ eV}$) has less deleterious effect on the ductilities of the zirconium-niobium alloys than on that of cold-worked Zircaloy-2.
4. Impact properties of the alloys have been determined both before and after irradiation, with hydrogen concentrations up to 250 ppm. Comparative studies between cold-worked Zircaloy-2 and the heat-treated zirconium-niobium alloys show the latter to absorb more energy at fracture.
5. The creep behaviour of the heat-treated Zr - 2.5wt% Nb alloy is characterized by a minimum rate of $5 \times 10^{-6} \text{ \% / h}$ at 21 kgf/mm^2 and 300°C. Results on the Zr - 2.5wt% Nb - 0.5wt% Cu alloy indicate a creep rate slightly higher than for the binary alloy.

6. The corrosion behaviour has been evaluated for water, steam, air and carbon dioxide, at temperatures in the range 260-500°C. Post-transition weight gains in purified static water at 316°C are in the ranges 0.2-0.25 and 0.07-0.08 mg/(dm² day) for the Zr - 2.5wt% Nb and Zr - 2.5wt% Nb - 0.5wt% Cu alloys respectively. Corresponding hydrogen pick-up for the Zr - 2.5wt% Nb alloy is 2.5-4.5 µg/(dm² day). These values apply to material quenched from the β-phase and tempered 24 h at 500°C; similar rates are indicated when the alloys are in the preferred heat-treated conditions. Higher corrosion rates are found in flowing water at 288°C and pH 8-10 (adjusted by ammonia or lithium hydroxide). The corrosion behaviour of the Zr - 2.5wt% Nb - 0.5wt% Cu alloy in both air and moist carbon dioxide at 300°C is similar to that of Zircaloy-2; the corresponding behaviour for the Zr - 2.5wt% Nb alloy has been variable. The corrosion resistance of the Zr - 2.5wt% Nb alloy is improved by cold working between the quench and temper treatments.
7. A number of Zr - 2.5wt% Nb tubes, 5 m long with a 3-mm wall thickness, have been fabricated and heat-treated. These tubes have a burst strength at 300°C of >74 kgf/mm² with 15% reduction in area at point of rupture. Development programs are proceeding on fabrication of Zr - 2.5wt% Nb coolant tubes.
8. Coolant-tube spacers of heat-treated Zr - 2.5wt% Nb - 0.5wt% Cu alloy will be used in the CANDU reactor.